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HEAVY RESIDUE PRODUCTION IN HEAVY ION INDUCED REACTIONS ON ^{124}Sn BETWEEN 10 AND 84 MeV/NUCLEON

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Résumé - Les spectres en vitesse des résidus lourds émis dans les réactions ^{12}C , ^{20}Ne , $^{40}\text{Ar} + ^{124}\text{Sn}$ ont été mesurés entre 0° et 10° , à plusieurs énergies du domaine 10-84 MeV/nucléon. Les données sont en accord avec l'hypothèse d'un processus de fusion incomplète asymétrique.

Abstract - Heavy residue velocity spectra of ^{12}C , ^{20}Ne , $^{40}\text{Ar} + ^{124}\text{Sn}$ reactions induced in the 10-84 MeV/nucleon energy range have been measured between 0° and 10° . Asymmetric incomplete fusion process calculations are in agreement with the data.

A limitation of the linear momentum transfer in central heavy ion collisions has been observed in a lot of various experiments performed at intermediate energy /1,3/. In other words, the complete fusion process becomes less and less probable as the incident energy increases. To follow progressively the evolution of the more central processes, we have focused our effort on a series of systematic velocity measurements of ^{124}Sn target-residues recoiling between 0° and 10° . The aim is to precise, as far as possible, the respective parts of projectile and target participating to the formation of the fused systems which precede the emission of heavy residues.

In this paper, we present in details a set of results on the $^{20}\text{Ne} + ^{124}\text{Sn}$ system and we apply simple incomplete fusion calculations, in the frame of reasonable assumptions, to reproduce the data at the best. Then, the treatment is extended to mass-velocity spectra observed for other systems as $^{12}\text{C} + ^{124}\text{Sn}$ or $^{40}\text{Ar} + ^{124}\text{Sn}$.

The experiments were performed with various heavy ions, at different energies. The beams were delivered by several accelerators (ALICE : 10 MeV/nucleon, SARA : 20-30 MeV/nucleon, GANIL : 27-60 MeV/nucleon, SC at CERN : 49 and 84 MeV/nucleon).

The technique was based upon off-line gamma-activity measurements following target irradiations associated with on-line collection of reaction products /4/. Heavy residues emitted around the beam axis were collected by a stack of thin aluminium foils (1 or 2 μm thick) set behind a thin ($400 \mu\text{g} \times \text{cm}^{-2}$) target, perpendicularly to the beam axis. A collimator placed between the target and the catchers defined a solid angle of 95 msr ($\theta = 0^\circ - 10^\circ$). The identification of the reaction products with $70 \lesssim A \lesssim 130$ masses was precisely established from the analysis of γ -ray activity measurements of all catchers. The velocity distributions were extracted, by use of range tables.

The mass-velocity spectra obtained for residues emitted between 0° and 10° in the $^{20}\text{Ne} + ^{124}\text{Sn}$ reaction at 20, 30, 40 and 49 MeV/nucleon are shown in figure 1. On these diagrams, one observes clearly that, at each bombarding energy, the most probable velocity of the residues, V_p , although relatively high, is lower than the center of mass velocity V_{cm} . This indicates that, for all incident energies, the final products correspond to evaporation residues coming from incomplete fusion mechanisms. Moreover, with increasing incident energy, the difference between V_p and V_{cm} increases, indicating that the involved momentum transfer is more and more incomplete.

As the residues have been measured between 0° and 10° , they have been initia-

ted with parallel momentum transfer respect to the beam axis ($p_{\perp} \approx 0$) and the velocity of the formed fusion-like nucleus is not significantly perturbed by the following evaporation ($V_{\text{residue}} \approx V_{\text{fusion-like nucleus}}$). In first approximation, the expe-

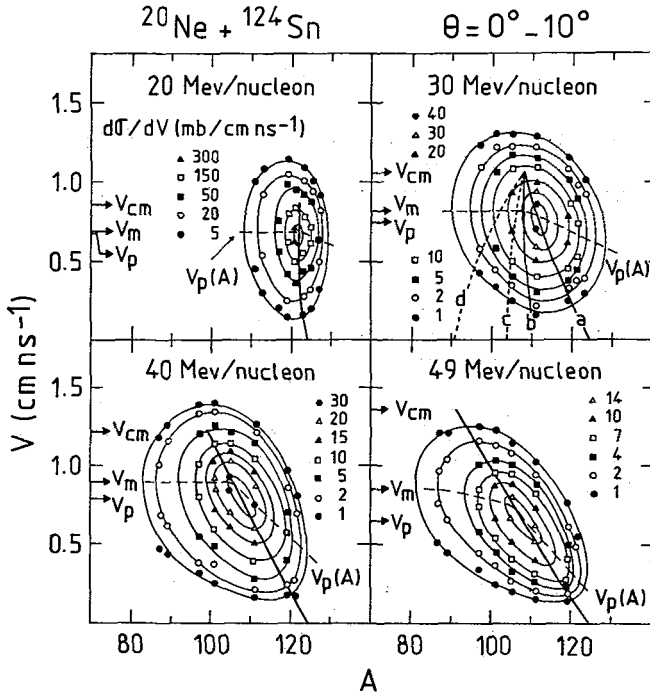


Fig. 1 - Mass-velocity spectra of residues emitted between 0° and 10° for $^{20}\text{Ne} + ^{124}\text{Sn}$ at 20, 30, 40 and 49 MeV/nucleon. V_{cm} is the center of mass velocity ; V_m is the most probable velocity measured for the lower masses and V_p is the most probable velocity of the distribution integrated over all masses. $V_p(A)$ (---) represents the evolution of the measured most probable energy as a function of mass ; see the text for the curves labelled a, b (—) and c, d (-----).

rimental results can be compared with V and A values calculated in simple incomplete fusion models where only a few parameters are used. To estimate the velocity V and the mass A of the residues, several assumptions can be done to realize the formation of the fusion-like nucleus.

In the "asymmetric hypothesis", a part of the projectile fuses with the totality of the target. The spectator nucleons of the projectile are emitted (as nucleons, clusters or unique quasi-projectile fragment) in the beam direction, with the projectile velocity V_p (case labelled a) or with a part of the incident velocity (for example 80 %, case labelled b).

In the "symmetric hypothesis", a part of the projectile fuses with a part of the target with the assumption that the same number of nucleons are escaping from the target as from the projectile. In this hypothesis, two reasonable situations have been treated for the spectator nucleons : in the first case they are emitted along the beam axis with their initial velocities, namely V_p , for the projectile nucleon (case labelled c) ; in the second case, it has been fixed that they are emitted with 80 % of V_p if they correspond to projectile nucleons and with 20 % of V_p for target

nucleons (case labelled d). Assuming a reasonable value for the average energy carried away per evaporated nucleon (typically between 13 and 16 MeV), we can estimate the velocity V and the mass A of the residues from the momentum and energy conservation relations /3/.

Calculations of velocity and mass values have been done for the residues produced in the $^{20}\text{Ne} + ^{124}\text{Sn}$ reaction at 30 MeV/nucleon in the four above mentioned cases and with a number of involved projectile nucleons varying from 0 to 20. The results are drawn in figure 1 for the 30 MeV/nucleon mass-velocity spectrum. It appears clearly that the calculated curve labelled "a" fits quite well the experimental A,V distribution while the three other estimations disagree significantly.

To lighten the 20, 40 and 49 MeV/nucleon mass-velocity diagrams, the solid lines drawn correspond to values calculated in the frame of the "asymmetric hypothesis" and case "a" (fig. 1). One sees that the agreement between the experimental A,V distributions and the calculated ones is quite good.

In conclusion, for the $^{20}\text{Ne} + ^{124}\text{Sn}$ system, from 20 to 49 MeV/nucleon, an incomplete fusion process where a part of the projectile fuses with the target while the spectator nucleons are emitted along the beam axis with the incident velocity, is in agreement with the experimental mass-velocity spectra of the residues observed between 0° and 10° . Especially, the evolution of the distributions, with increasing incident energy, is remarkably well reproduced. Nevertheless, as the measurements have been made in the 0° - 10° range, reactions with very small perpendicular momentum transfers have been predominantly selected and so, we cannot say that all incomplete fusion collisions lead to the emission of fast particles having the projectile velocity. One can only conclude that the "asymmetric hypothesis" is probably the best assumption for the whole of the incomplete fusion collisions.

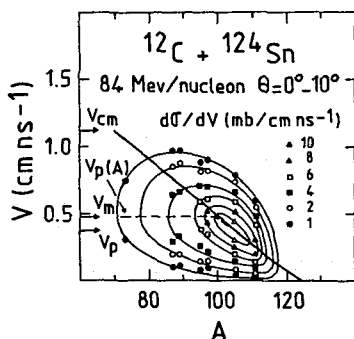


Fig. 2

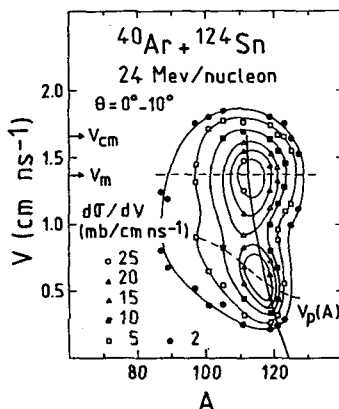


Fig. 3

Same as fig. 1 for other systems.

To check the applicability of this hypothesis, comparisons have been made for A,V experimental residue distributions measured with various projectiles. Typical examples are reported for $^{12}\text{C} + ^{124}\text{Sn}$ at 84 MeV/nucleon (fig. 2) and $^{40}\text{Ar} + ^{124}\text{Sn}$ at 24 MeV/nucleon (fig. 3). In both cases, the "asymmetric hypothesis" remains a good approach to fit the experimental mass-velocity spectra at small angles (0° - 10°). The comparison is specially interesting in the $^{40}\text{Ar} + ^{124}\text{Sn}$ case. Between 24 and 35 MeV/nucleon, the velocity spectra exhibit two different components. From the comparison between A, V experimental results and "asymmetric hypothesis" calculations, the situation appears more simple and mainly dominated by only one incomplete fusion mechanism.

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